The Upper-Layer Circulation of the Japan Sea and the Arabian Marginal Seas and Gulfs: Historical Data Analysis

Dr. Amy S. Bower
Department of Physical Oceanography, MS#21
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
phone: (508) 289-2781 fax: (508) 457-2181 email: abower@whoi.edu

Award #: N00014-98-1-0184
Award #: N00014-00-1-0688
http://science.whoi.edu/users/abower

LONG-TERM GOAL

The circulation of the Japan Sea is characterized by significant temporal and spatial variability due to several factors, including seasonal fluctuations in the warm inflow through Tsushima Strait, branching of the Tsushima Warm Current downstream of the strait, and the formation of mesoscale eddies along these branches. The long-range objective of the Japan Sea study is to understand the dynamical processes that govern this variability. The long-range objective of the Arabian Marginal Seas and Gulfs (AMSG) study is to better understand the relationship between the vigorous atmospheric forcing of the AMSG and the response of the upper ocean in order to be able to better predict the evolution of water properties and upper ocean currents.

OBJECTIVES

Our objectives for the Japan Sea work are to:

1. Describe the synoptic three-dimensional structure of the branching of the Tsushima Warm Current and its seasonal variability.

2. Describe the spatio-temporal modes of variability in dynamic height and determine the primary sources of this variability.

3. Provide a better description of the origin of the Tsushima Warm Current in the East China Sea and seasonal variability in its T-S characteristics.

For the AMSG work, our objectives are:

1. To investigate the seasonal variability in water mass characteristics and distributions in the Arabian Gulf.

2. To describe the structure and seasonal variability of the major fronts and eddies in the upper ocean of the Gulf of Oman and northern Arabian Sea.

3. To examine the spatial and temporal characteristics and origin of the large, anticyclonic eddies found regularly in the Gulf of Aden through data analysis and data-model comparison.

APPROACH

We are using historical hydrographic data from Dr. Alison Macdonald's North Pacific climatology and the vast XBT/AXBT data set from NAVOCEANO to investigate the seasonal variability in dynamic height in the Japan/East Sea. A method developed by Lagerloef (1994) is being used to convert temperature profiles to dynamic height profiles. Modal analysis of the dynamic height fields will follow, with comparisons to the wind fields. We will also use the repeated, synoptic AXBT surveys archived at NAVOCEANO to investigate the synoptic circulation in the upper Japan Sea.

We are similarly making use of historical hydrographic and AXBT data from NAVOCEANO to examine the spatial and temporal variability of water properties in the AMSG region. We also plan to collaborate with John Kindle at NRL in the investigation of the Gulf of Aden eddies using the NRL Indian Ocean model that assimilates altimetric data.

WORK COMPLETED

This year we continued with the analysis of the NAVOCEANO data. The work in the Japan Sea focused on the description of intrathermocline eddies, in collaboration with Dr. Arnold Gordon.

RESULTS

The archive of hydrocast and XBT data from the Naval Oceanographic Office is being used to examine the upper-layer baroclinic circulation in the Japan/East Sea on seasonal time scales. The goal of this research is to define the climatological annual circulation cycle and to find the relationship between this cycle and external forcing, such as wind. To study the upper-layer circulation we have developed a dynamic height database derived from hydrocast data and XBT data, which has been converted to dynamic height using the 'mode method' developed by Lagerloef (1994). Preliminary observations of the T-S characteristics of the hydrocast data indicate that upper-layer variability is confined to the top 500 meters of the water column. A linear relationship was found between 300 and 500 dbar dynamic height, and we therefore found the 0 to 300 dbar integration range to adequately capture the variability in the upper-layer circulation enabling us to use the majority of NAVOCEANO's archived XBT data. Accuracy obtained using the Lagerloef method for the Japan Sea region is 0.03 dynamic meters. With the combined hydrocast and XBT dynamic height data set, which spans the years 1945 – 1995, we are investigating the seasonal circulation, as well as any decadal or intra-decadal changes in the seasonal cycle. We will also use EOF analyses to study the statistical relationship between the annual circulation and wind stress curl cycles, determining the extent to which Ekman pumping drives the upper-layer baroclinic circulation seasonally. Preliminary results from this work were presented at the Japan Sea PI Meeting at Stennis Space Center in October 1999.

An inventory of intra-thermocline eddies (ITE) has been made in the Japan Sea from six air-deployed XBT surveys from 1992 through 1995. The eddies, characterized in the XBT data by homogenous cores of greater than 100 meter thickness and mean temperatures of less than 12°C, have also been observed in other data to have a positive oxygen anomaly and negative salinity anomaly compared to surrounding thermocline water. The ITE properties indicate winter formation within the Japan Sea polar front, and subsequent subduction under the thermocline to the south. The AXBT surveys show two distinct ITE temperature groupings, one group having temperatures between 10 and 12°C, and the second (less common) around 7°C.   The seasonally-repeated synoptic AXBT surveys allow us to see possible formation and follow the movement and water mass modification of the individual ITEs. The AXBT surveys indicate formation can occur in both winter and spring, with complete subduction taking less than three months. The core temperatures of the ITEs can be directly linked to surface temperature at the formation site, and the ITEs appear to translate 1.1 ± 0.4 cm/sec to the south-southwest after formation. These observations confirm the working hypothesis of ITE formation along the polar front.

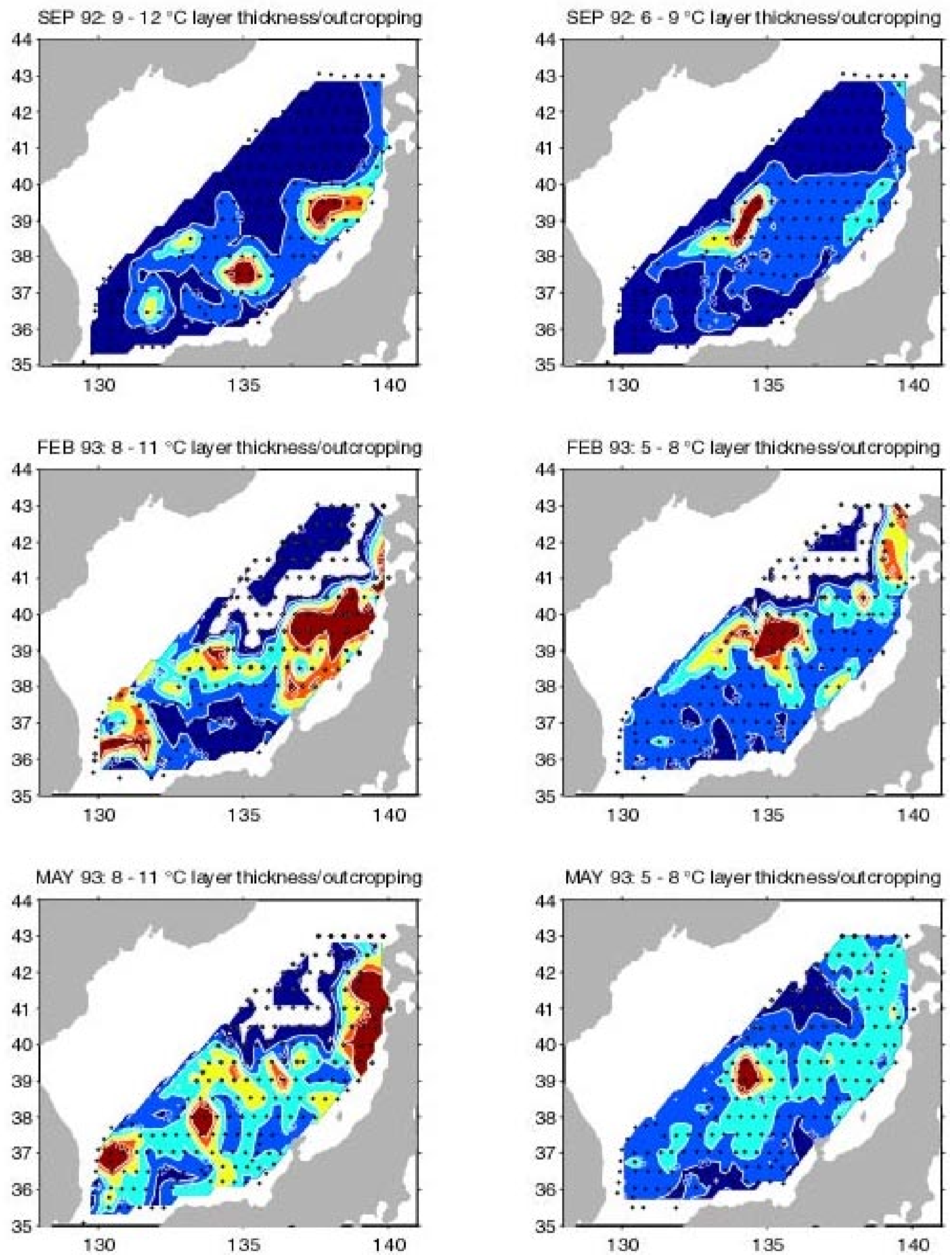

Figure 1: Thickness maps from three example AXBT surveys, from September 1992 to May 1993.

Each survey has two panels, depicting the thicknesses (in meters) of the 'warm' and 'cold' Intra-Thermocline Eddy (ITE) layers. The station locations are designated by solid or open dots. If a layer is submerged, then the station marker is designated by a black dot. If the upper temperature of the layer has outcropped, then the station is marked with an open circle. For example, in September 1992, no outcropping occurs, and all data represent the layer thickness. In February 1993, some northern stations have outcropped, and those stations represent the depth of either the 8degC or 5degC isotherm. In cases where there is no data, but a station marker exists, the lower isotherm has outcropped as well. By using this plotting technique, we see what may be ITE formations. For example, using the cold thickness/outcropping plots for February and May 1993, the central ITE (~39N 135E) was beginning to subduct in February and became completely subducted by May.

IMPACT/APPLICATIONS

Our results will provide a better description of the water properties and seasonal variability in the upper-ocean circulation of the Japan/East Sea and the AMSG, and its causes. The intrathermocline eddies described above were heretofore not identified in the eextensive AXBT surveys. They may play an important role in the flux of properties across the subpolar front in the Japan Sea.

RELATED PROJECTS

We plan to collaborate with other PIs working within the Departmental Research Initiative in the Japan Sea. Our work will relate particularly to that of Drs. Watts and Wimbush who will be making new observations of the mesoscale variability in the southern Japan Sea, as well as Dr. Arnold Gordon who is investigating intrathermocline eddies in recent hydrographic observations. Our study of Gulf of Aden eddies will help in the evaluation of NRL's Indian Ocean model that assimilates altimetric data.

REFERENCES

Lagerloef , G. S., 1994. An alternate method for estimating dynamic height from XBT profiles using empirical vertical modes. *Journal of Physical Oceanography*, **24**, 205-213.